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Transportation Research Procedia 14 (2016) 679 – 684

Transportation Research Procedia

www.elsevier.com/locate/procedia

6th Transport Research Arena April 18-21, 2016

The performance of a highly modified binders for heavy duty asphalt pavements

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Abstract

Long-lasting asphalt pavements as a concept arose in the late XX century. According to assumptions it is possible to achieve durability even for 50 years. The key to achieve so long-lived is appropriate choice of an asphalt binder, except for the relevant properties of asphalt mixtures. A few years ago a new family of highly modified binders was created which was characterized by reversed-phase of polymer-bitumen mixture, and it is now a perfect example of a binder which fulfil the pavement longevity assumptions concept. Based on a new, special polymer which was developed by polymer industry, a new family of binders – Highly Modified Asphalts (HiMA), has been developed – 'hard' (EN 25/55-80, PG 94-22), 'middle' (EN 45/80-80, PG 82-28) and 'soft' (EN 65/105-80, PG 76-28). All binders were tested according to very wide test program. Results confirmed superior performance of tested binders and their very positive influence on asphalt. The paper presents tests results and analysis of polymer modified binders, HiMA type. The research has been done based on the European standards and according to the Superpave (PG grade system).

Peer-review under responsibility of Road and Bridge Research Institute (IBDiM)

Keywords: Highly modified asphalt; long lasting asphalt pavements; Superpave; PMB

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Peer-review under responsibility of Road and Bridge Research Institute (IBDiM)
doi:10.1016/j.trpro.2016.05.331

1. Introduction

Research conducted by numerous academic centers over recent decades has corroborated the claim that higher polymer content in binder produces additional quality benefits, substantially contributing to the durability improvement of asphalt pavements in terms of cracking & rutting resistance, and fatigue. Particularly encouraging was exceeding the limit of polymer (typically SBS – Styrene-Butadiene-Styrene) content (about 7% by mass), after which the polymer phase in the polymer-modified binder becomes continuous. However, such a significant quantity of SBS for binder modification carried with it specific technical consequences for the production and application of modified binder, connected with following aspects:

- stability problems during the storage and transport of modified binder,
- very high viscosity of polymer modified binder, which cause a need for higher temperatures and some problems on building site.

The above limitations were decreased by special polymer type – low viscous SBS with vinyl groups, which was developed specially of highly-modified binder (or Highly Modified Asphalt - HiMA).

2. Principle of HiMA

Research and implementation work on new highly modified binders with a new type of polymer have shown that they are products above standard functional properties, characterized by, inter alia, very good resistance to rutting, water and frost and excellent fatigue strength and cracking resistance [Timm et al. 2012, 2013; Kluttz et al. 2013; Willis et al. 2012; Scarpas et al. 2012].

In terms of structure, courses with HiMA maintaining high tolerance to increasing tensile strains (so-called fatigue strains) [Kluttz et al. 2009; West et al.] thus potentially allowing a reduction in the thickness of the set of asphalt courses. Full-scale testing conducted since 2009 on the experimental track in the US (NCAT Pavement Test Track) showed that the experiment based on reducing pavement thickness by 18% and simultaneous use of a highly modified, special HiMA binder was a success – the surface proved to be resistant to rutting and fatigue cracking [West et al. 2012].

The primary purpose behind highly-modified binders is to counteract pavement cracking and plastic deformations (rutting), and to increase the fatigue resistance of asphalt courses. The continuous polymer network (polymer phase), acting in the binder and bituminous mix as an elastic element, which strongly restricts crack propagation in asphalt mixture.

Since 2011, the three new highly-modified binders have been developed as a result of laboratory work and production tests. The purpose and applications of these PMBs are presented in table 1.

Table 1. PMB HiMA applications.

	Applications
25/55-80 HiMA	Typical asphalt base courses and asphalt base courses of long-life pavements (type: perpetual pavement), high modulus mixtures (EME/HMB).
45/80-80 HiMA	Wearing courses and binder courses of pavements exposed to very heavy loads and working at low temperatures, as well as for other courses in specific places, e.g. on bridges
65/105-80 HiMA	Special technologies, e.g. SAMI courses, for the production of asphalt emulsions used in slurry seal; because of its high penetration.

HiMA can be used in technologies and locations for which the required durability is very high.

3. PMB HiMA test results

Asphalt mixtures made with the HiMA have been tested in the course of laboratory works, process tests and road trial sections. Below are presented test results of the HiMA binders.

3.1. Basic test results as per EN 14023

Table 2. shows the selected required properties of PMB HiMA in reference to the methods from EN 14023.

Table 2. The test results of PMB HiMA as per EN 14023.

Property		Test method	Unit	25/55-80 HiMA	45/80-80 HiMA	65/105-80 HiMA
				Test result	Test result	Test result
Penetration at 25 °C		EN 1426	0,1 mm	41	66	87
Softening point R&B		EN 1427	° C	95.0	92.0	87.2
Cohesion	Force ductility by ductilometer method (tension of 50 mm/min.)	EN 13589 EN 13703	J/cm^2	5.5 (at 15 °C)	3.7 (at 10 °C)	3.5 (at 10 °C)
Breaking point (Fraass)		EN 12593	°C	-16	-20	-22
Elastic recovery	at 25 °C	EN 13398	%	90	96	95
	at 10 °C	EN 13398	%	71	76	85

3.2. Test results of low-temperature properties

In the Performance Grade system, the Bending Beam Rheometer (BBR) was used to test binder behavior at low temperatures.

Table 3 presents low-temperature property testing results, with the test carried out by the Bending Beam Rheometer, and the samples aged in RTFOT and PAV.

Table 3. Low-temperature results for PMB HiMA binder ageing (RTFOT+PAV), by the BBR at S(60) = 300 MPa, m(60) = 0.3 and stiffness S at -16 °C).

Binder type	Critical temperature at S(60) = 300 MPa T(S)60 [°C]	Critical temperature at m(60) = 0.3 T(m)60 [°C]	Binder stiffness at -16 °C S(T)-16 [MPa]
	EN 14771 AASHTO PP 42	EN 14771 AASHTO PP 42	EN 14771 AASHTO PP 42
25/55-80 HiMA	-18,5	-16,2	229,5
45/80-80 HiMA	-19,7	-19,8	181,3
65/105-80 HiMA	-20,6	-20,8	171,3

Additionally, the low temperature properties were checked in TSRS test according to EN 12697-46 on asphalt concrete AC 16 for binder courses. The same mineral mixtures with different binders were tested in order to compare critical cracking temperature.

The results are presented in table 4.

Table 4. Low-temperature results for AC 16 with PMBs HiMA; TSRST method acc. to EN 12697-46, -10 K/h.

Binder type	Critical cracking temperature [°C]	Critical stress [MPa]
	EN 12697-46	EN 12697-46
25/55-80 HiMA	-33,9	4,7
45/80-80 HiMA	-35,9	4,6
65/105-80 HiMA	-36,9	4,2

3.3. Test results of high-temperature properties

Resistance of the binder to high temperatures was determined in Dynamic Shear Rheometer (DSR)
Table 5 presents the DSR test results for the relevant properties. Test parameters:

- complex stiffness modulus G* and angle phase δ of the not aged binder to determine critical temperature at G*/sin δ =1 kPa,
- complex stiffness modulus G* and angle phase δ of the binder after RTFOT to determine critical temperature at G*/sin δ =2.2 kPa, of the binder after RTFOT.

Table 5. The DSR test results.

Binder type	Critical temperature at G*/sin δ =1 kPa binder prior to RTFOT [°C]	Critical temperature at G*/sin δ =2.2 kPa binder after RTFOT [°C]
	AASHTO T 315	AASHTO T 315
25/55-80 HiMA	105,2	95,4
45/80-80 HiMA	98,2	84,3
65/105-80 HiMA	94,3	77,4

Apart from binders' test according to Superpave method, the routine rutting test according to EN 12697-22 (small apparatus, 60 °C, 10000 cycles, in air) has been executed. The results (showed in table 6) confirmed very good resistance of asphalt concrete mixtures for plastic deformation.

Table 6. The rutting test results of AC 16 with HiMA binders.

Binder type	WTSair [mm/1000 cycles]	RD [mm]
	EN 12697-22	EN 12697-22
25/55-80 HiMA	0,05	2,1
45/80-80 HiMA	0,06	2,6
65/105-80 HiMA	0,09	3,1

4. Experimental sections in Poland

In October 2013, the first experimental section of road pavement with PMB 65/105-80 HiMA was completed in Poland. This was the 6th section constructed with HiMA in Europe and the first in Poland. Two wearing course sections were placed, one made of AC 11 (layer thickness of 4 cm), and the other of a special SMA 5 DSH mix (so-called ultra-thin "silent" pavement, 2 cm thick wearing course). These trial sections provided a lot of process data:

- production at the asphalt plant should take place in the same temperature as with conventional PMB mixtures,
- compaction on the road of asphalt mixtures with highly-modified HiMA binder need more attention especially when compaction is realized in colder weather period,
- hand-working areas should be avoided,
- all equipment should be cleaned as soon as possible, when asphalt mixtures is still warm. .

In 2014 and 2015, successive sections incorporating another type of HiMA binder: PMB 45/80-80 HiMA were completed. These were:

- August 2014, road No.793 in Poland, length 1 500 m, wearing course of AC11 and SMA 5 DSH,
- October 2014, road No.928 in Poland, length 800 m, wearing course of SMA 11 on a railway bridge deck,
- October 2014, road by-pass in Poland, length 1 000 m, wearing course of SMA 11,
- June/July 2015, highway No. A4 in Poland, length 14 000 m, wearing course of SMA 11,
- 2015, more than 10 sections in Silesia region, different courses, including full depth asphalt constructions with PMB HiMA.

5. Conclusions

Highly modified asphalt PMB HiMA is a binder dedicated to applications requiring binders with very high performance:

- asphalt pavements subjected to high strains, e.g.: on bridge decks,
- top layer with resistance to low temperatures,
- thin and ultra-thin wearing courses,
- asphalt base-courses with very high fatigue strength, e.g.: for long-lasting pavement types as „perpetual pavements".

Results of tests proved the HiMA binders could be applied in a wide range of pavement temperatures. Low temperature properties, as per BBR test, showed that binder is resistant to temperature induced cracks. It is worth to see that both BBR parameters (m and S) for 'medium' and 'soft' PMB HiMA are not only low but with close values as well. From the other hand the rutting test results showed that all HiMA binders present extremely good rutting resistance.

We have seen an increase of traffic loading in terms of numbers of passing vehicles, but also of an increased share of the maximum axle loads. On the other hand the investors and road users are setting higher requirements (warranty periods of up to 10 years for instance). So we thus face an increasing challenge that calls for smart solutions either in mix or binder quality or both. New modified binders with increased polymer levels (HiMA) are able to comply with these high requirements.

Acknowledgements

All tests presented in the publication were conducted at:

- ORLEN Laboratorium Sp. z o.o. (laboratory accredited in PCA No. AB 484), Plock, Poland
- Research Institute of Inorganic Chemistry, Inc. (VÚAnCh), Czech Republic
- Gdansk University of Technology, Faculty of Civil Engineering and the Environment, Gdansk, Poland
- Ekonaft sp. z o.o. (laboratory accredited in PCA No. AB 496), Trzebinia, Poland

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